DFMA Cost Estimates of Fuel-Cell/Reformer Systems at Low/Medium/High Production Rates

Brian D. James (Primary Contact), Gregory D. Ariff, Reed C. Kuhn, and Duane B. Myers
Directed Technologies, Inc.
3601 Wilson Boulevard, Suite 650
Arlington, VA 22201
Phone: (703) 243-3383; Fax: (703) 243-2724; E-mail: Brian_James@DirectedTechnologies.com

DOE Technology Development Manager: Nancy L. Garland
Phone: (202) 586-5673; Fax: (202) 586-9811; E-mail: Nancy.Garland@ee.doe.gov

ANL Technical Advisor: Walter Podolski
Phone: (630) 252-7558; Fax: (630) 972-4430; E-mail: podolski@cmt.anl.gov

Objectives

- Develop realistic and internally consistent detailed designs for automotive gasoline fuel processor/ proton exchange membrane (PEM) fuel cell systems and direct hydrogen PEM fuel cell systems by using current-year technology.
- Apply Design for Manufacture and Assembly (DFMA) design and costing techniques to compare system designs at low, medium, and high annual production rates.
- Develop a roadmap to lower system cost by performing a sensitivity study of the major components in the fuel processor and fuel cell systems.
- Determine the impact on cost, volume, and mass of replacing the fuel processor unit operations with microchannel-type components.

Technical Barriers

This project addresses the following technical barriers from the following sections of the Hydrogen, Fuel Cells and Infrastructure Technologies Program Multi-Year R,D&D Plan:

Hydrogen Production

- A. Fuel Processor Capital Costs

Hydrogen Delivery

- A. Lack of Hydrogen/Carrier and Infrastructure Options Analysis

Fuel Cells

- D. Fuel Cell Power System Benchmarking

Approach

- Conduct annual updates of design, manufacturing methods, and costs for the four 50-kW_{net} PEM fuel cell systems previously examined:
  - reformer/fuel cell system operating at 0.7 V/cell peak-power
  - reformer/fuel cell system operating at 0.6 V/cell peak-power
  - direct hydrogen fuel cell system operating at 0.7 V/cell peak-power

  - direct hydrogen fuel cell system operating at 0.6 V/cell peak-power
- Perform cost sensitivity analysis for material costs and system performance parameters.
- Analyze weights, volumes, and costs of microchannel device substitutes for reformer components and compare to baseline design.

Accomplishments

- Performed annual update to cost estimates of baseline and three alternative systems with more detailed estimates of peripheral components.
- Conducted a sensitivity study to quantify the overall fuel cell cost reductions that could result from cost reductions and technological improvements in major fuel processor and fuel cell system components.
- Compared microchannel designs for the major fuel processor components (catalytic reactors and heat exchangers) with the existing baseline designs, with a focus on component mass and volume.

Future Directions

- Update baseline reformer and fuel cell cost estimates to reflect advances in technology and additional manufacturing and design improvements.
- Construct a roadmap to lower system cost based on the results of the sensitivity study.
- Analyze potential cost reductions resulting from gas purification technologies.
- Examine feasibility of alternate fuel cell designs and operations, such as stack construction, voltage and/or pressure pulsing, and air compression technologies.
- Identify feasible manufacturing techniques and costs for microchannel fuel processor components.

Introduction

Directed Technologies Inc. (DTI) has performed a DFMA-style cost estimation for an onboard gasoline reformer and fuel cell system at several annual production volumes. The Design for Manufacture and Assembly (DFMA) technique is a rigorous design/redesign and cost estimation methodology developed by Boothroyd and Dewhurst (1) and adapted by DTI. DTI has previously analyzed the cost of a 50-kW_{net} baseline system and compared it to an alternate reformer/fuel cell system and two direct hydrogen fuel cell systems.

The current report provides updates to the estimated costs for these four systems, a sensitivity analysis aimed at identification of cost reduction options in the baseline system, and a summary of the evaluation of microchannel technology for possible use in the fuel processor system. Microchannel component design takes advantage of the high specific heat transfer area that can be achieved through the use of reaction and heat exchange devices that have flow channels with critical dimensions of less than 1 millimeter.

Approach

System Cost Updates. Using information gained over the past year related to the cost of fuel cell (FC) materials and components as well as interactions with industry, the cost of the baseline 0.7 V/cell reformer-FC system, the 0.6 V/cell reformer-FC system, and both the 0.6 and 0.7 V/cell direct hydrogen systems have been updated. While the newest cost estimates are slightly different than previous ones, the trends and conclusions drawn in previous years remain unchanged.

Cost Sensitivity Analysis. With the intent of developing a roadmap to lower system cost, we examined the sensitivity of system cost to various material costs and performance parameters for both the reforming system and the fuel cell stack. The relative cost contribution of the following materials was examined:

- Stack components: ionomer, gas diffusion layer (GDL), and bipolar plates
- Precious metal (PM) catalysts in the fuel cell stack, reforming and gas-cleanup sections
- Reformer shell materials
- Reformer catalyst support and application

Using a component-by-component parametric model, the sensitivity of system cost to the following parameters was evaluated:

- Stack power density
- Overall system efficiency
- Reformer, water gas shift (WGS), and preferential oxidation (PrOx) bed volumes
- Gasoline sulfur levels

Microchannel Technology Assessment. We have considered microchannel devices as replacements for the following fuel processor subsystems:

- Autothermal reformer/steam reformer (ATR/SR)
- High-temperature water gas shift (HTS)
- Water boiler/vaporizers (2 items)
- Low-temperature water gas shift (LTS)
- Preferential oxidation (PrOx)

The subsystems listed above were screened through discussions with Pacific Northwest National Laboratory (PNNL) and by preliminary design calculations to determine which processing steps could benefit by the substitution of microchannel devices.

Results

System Cost Updates. The system cost breakdowns for the 0.7 V/cell reformate and direct hydrogen systems are shown in Figure 1. In both systems, the fuel cell stack contributes roughly half the cost of the complete system.

Cost Sensitivity Analysis. In a fixed system design, material costs for various components provide an estimate of the relative potential for system cost reductions through material cost reductions. The results of the materials cost analysis are shown in Figure 2, where membrane ionomer, membrane catalyst, GDL, and bipolar plate are shown to be the largest cost-contributing materials.

Figure 3 is a tornado plot for several system performance parameters, indicating that fuel cell stack power density (and, hence, active area) is the most significant performance parameter affecting system cost. The data shown correspond to the 0.7 V/cell reformer-FC system at a manufacturing rate of 500 units per year but are nearly identical at a manufacturing rate of 500,000 units per year.

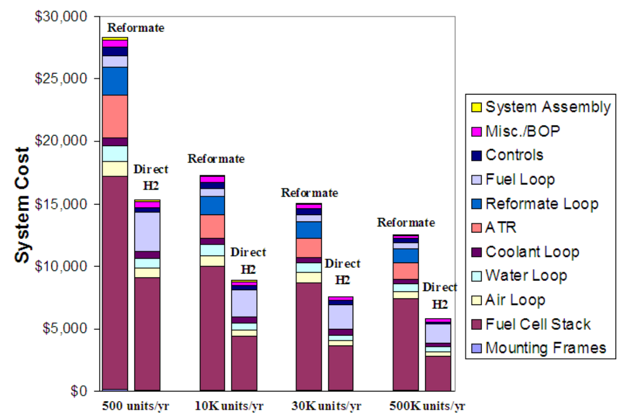

Figure 1. Cost Breakdown for 0.7 V/cell Reformer-Fuel Cell and Direct Hydrogen Systems

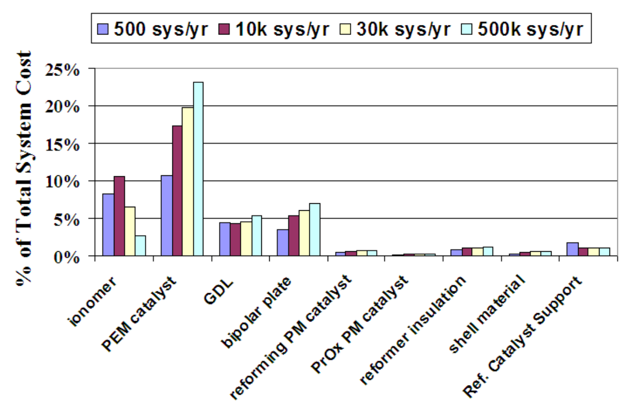

Figure 2. Contribution of Material Costs to System Costs for Baseline Reformer-Fuel Cell System

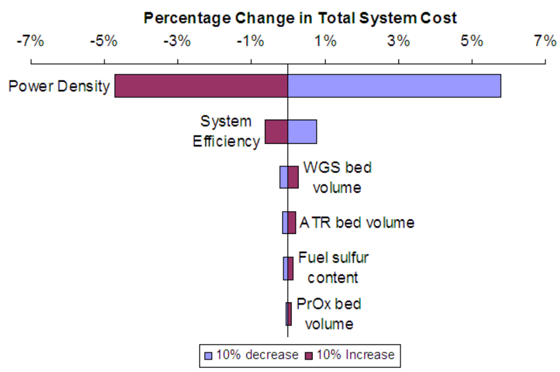

Figure 3. Effect of Operational Parameters on System Cost at Production Rate of 500 Systems/Yr

Microchannel Technology. The autothermal reformer (ATR) was eliminated as a potential application for microchannel components due to the high temperatures involved (>800°C) that would require thick metal walls and because the adiabatic operation of the ATR is well-suited to using a ceramic monolith reactor. Additionally, design calculations indicate there is at most a 10% improvement in reactant mass transfer through the catalyst matrix in a microchannel with 750 mm flow paths compared to a monolith with 1 mm cells.

More substantial volumetric reduction is potentially achievable through conversion of the water vaporizer to a microchannel design. Such a design was prepared using 480°C reformate as the heating fluid to vaporize the water as in the baseline design. The core of the microchannel design achieved an 82% reduction in volume compared to the baseline design; however, when fluid manifolding is included, the volume reduction shrinks to 32% (669 cm^3 vs. 991 cm^3). This indicates, sensibly, that imaginative integration of components will be required to achieve maximum volumetric reduction, since manifolding can quickly erase much of the gains.

The microchannel water gas shift (WGS) reactor design combines the high temperature shift bed, water vaporizer, and low temperature shift bed from the baseline design into a single device. The integration of heat exchange and reaction allows the WGS reaction to trace the equilibrium curve from 400°C down to 300°C, resulting in a reduced catalyst volume compared to the baseline. Preliminary calculations show that a reduction in system volume of 68% is possible by using the microchannel design (4.2 liters vs. 13.0 liters). (The PNNL staff is in the process of reviewing the design for the microchannel WGS, and their comments will be considered before finalizing the design.) However, due to the addition of the metallic heat exchange elements, the mass of the microchannel core and the mass of the baseline system are estimated to be almost identical (12.6 kg vs. 12.7 kg).

Conclusions

The baseline design for this study was developed using DFMA-style techniques applied to the stack and fuel processing components to achieve low cost. In the resulting system, the fuel cell stack represents roughly half the system cost at all production rates. This fact is emphasized by both the material and performance parameter sensitivity analyses, in which fuel cell stack materials and power density are shown to be the most significant cost contributors. Substantial cost reductions in the system can only be achieved by addressing issues with the potential to reduce stack size, either directly through improved stack performance or indirectly through fuel processor improvement to deliver higher purity hydrogen to the stack. These approaches can be summarized as follows:

- Lower stack material and fabrication costs
  - lower catalyst loading
  - less expensive stack materials
- Increased stack power densities
  - improved membrane performance
  - improved stack operation
  - improved gas processing for pure hydrogen

Microchannel devices are potentially attractive for fuel processor subsystems that benefit from combined reaction and heat exchange. The water gas shift and preferential oxidation steps, therefore, are potential applications for microchannel technology, while the adiabatic autothermal reforming is not. An integrated microchannel WGS heat exchanger/ reactor can potentially achieve a nearly 70% volume reduction compared to the baseline non-integrated unit. Analysis to date suggests negligible, if any, mass reduction for the microchannel system compared to the baseline. The next step in the analysis is to use DFMA-style techniques to identify the most practical and cost efficient manufacturing processes and thereby determine the resulting system cost for the microchannel water gas shift reactor.

References

1. Boothroyd, G., Dewhurst, P., and Knight, W. Product Design for Manufacture and Assembly, Second Edition. Marcel Dekker, Inc. New York, 2002.

FY 2003 Publications/Presentations

1. Brian D. James at the FreedomCAR Fuel Cell Tech Team on September 18, 2002.
2. Brian D. James at the FreedomCAR Storage Tech Team on October 16, 2002.
3. Brian D. James at the SAE Congress in Detroit on March 5, 2003.
4. Brian D. James at the 2003 Merit Review and Peer Evaluation Meeting of the US DOE Hydrogen, Fuel Cells & Infrastructure Technologies Program on May 20, 2003.